

The Measurements of $J/\psi \rightarrow p\bar{p}$

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The process $J/\psi \rightarrow p\bar{p}$ is studied using 57.7×10^6 J/ψ events collected with the BESII detector at the Beijing Electron Positron Collider (BEPC). The branching ratio is determined to be $Br(J/\psi \rightarrow p\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$, and the angular distribution is well described by $\frac{dN}{d\cos\theta_p} = 1 + \alpha \cos^2\theta_p$ with $\alpha = 0.676 \pm 0.036 \pm 0.042$, where θ_p is the angle between proton and beam direction. The obtained α value is in good agreement with predictions of first-order QCD.
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I. INTRODUCTION

The J/ψ meson is interpreted as a bound state of a charmed quark and charmed antiquark ($c\bar{c}$). The decay process $J/\psi \rightarrow p\bar{p}$ is an octet-baryon-pair decay mode that has been measured by DM2 [1], DASP [2], Mark I [3], Mark II [4] and Mark III [5].

In general, the angular distribution of $J/\psi \rightarrow B\bar{B}$ can be written as

$$\frac{dN}{d\cos\theta_B} \propto 1 + \alpha \cos^2\theta_B,$$

where θ_B is the angle between the direction of the omitting baryon and the e^-e^+ beam direction. Different theoretical models based on first-order QCD give different predictions for the value of α [6, 7, 8]. Brodsky and Lepage [6] assumed that the reaction is a process in the asymptotic region where all quark and baryon masses can be neglected. Claudson, Glashow, and Wise [7] included the baryon masses in their calculation, which significantly changed the previous prediction. Carimalo [8] considered the effect of non-zero quark masses. The branching ratio and corresponding angular distribution will provide some insight into the details of the baryon structure [6, 7, 8, 9, 10]. Chernyak and Zhitnitsky [9] have investigated QCD sum rules for nucleon wave functions and calculated the branching ratio of the discussed decay in terms of the wave function. Ping, Chiang and Zou [10] studied the branching ratio as well as the angular distribution for $J/\psi \rightarrow B\bar{B}$ decay processes in naive quark model. Table I shows the measured branching ratio and α value of $J/\psi \rightarrow p\bar{p}$ by previous experiments. Table II shows the different theoretical predictions on α value.

TABLE I: Previous experimental results for $J/\psi \rightarrow p\bar{p}$

measured value about Br. and α			
Coll.	N^{obs}	Br($\times 10^{-3}$)	α
Mark1	331	2.2 ± 0.2	1.45 ± 0.56
Mark2	1420	$2.16 \pm 0.07 \pm 0.15$	0.61 ± 0.23
Mark3		$1.91 \pm 0.03 \pm 0.16$	0.58 ± 0.14
DASP	133	2.5 ± 0.4	1.70 ± 1.70
DM2		$1.91 \pm 0.04 \pm 0.30$	0.62 ± 0.11
PDG[14]		2.12 ± 0.10	$0.63 \pm 0.08(\text{avg.})$

TABLE II: Different theoretical predictions on α value

Theoretical values of α	
α	authors
1.0[6]	Brodsky and Lepage
0.46[7]	Claudson, Glashow and Wise
0.69, 0.70[8]	Carimalo

In this paper, we report high precision measurements of the branching ratio of $J/\psi \rightarrow p\bar{p}$ and corresponding

α value. The measurements are based on an analysis of $57.7 \times 10^6 J/\psi$ [13] events registered in the BESII detector at BEPC.

BESII is a large solid-angle magnetic spectrometer that is described in Ref. [11]. Charged particle momenta are determined with a resolution of $\sigma_p/p = 1.78\% \sqrt{1 + p^2(\text{GeV}^2)}$ in a 40-layer cylindrical main drift chamber (MDC). Particle identification is accomplished by specific ionization (dE/dX) measurements in the drift chamber and time-of-flight (TOF) measurements in a barrel-like array of 48 scintillation counters. The dE/dX resolution is $\sigma_{dE/dX} = 8.0\%$; the TOF resolution for Bhabha events is $\sigma_{TOF} = 180$ ps. These two systems independently provide more than 3σ separation of protons from any other charged particle species for the momentum range relevant to $J/\psi \rightarrow p\bar{p}$ decays. Radially outside of the TOF counters is a 12-radiation-length barrel shower counter (BSC) comprised of gas proportional tubes interleaved with lead sheets. The BSC measures the energies and directions of photons with resolution of $\sigma_E/E \simeq 21\%/\sqrt{E(\text{GeV})}$, $\sigma_\phi = 7.9$ mrad, and $\sigma_z = 2.3$ cm. The iron flux return of the magnet is instrumented with three double layers of counters that are used to identify muon.

In this analysis, a GEANT3 based Monte Carlo package (SIMBES) with detailed consideration of the detector performance (such as dead electronics channels) is used. The consistency between data and Monte Carlo has been carefully checked in many high purity physics channels, and the agreement is reasonable.

II. EVENT SELECTION

Events are selected with two and only two well reconstructed and oppositely charged tracks. The polar angle of the track, θ , is required to be in the range $|\cos\theta| < 0.8$. In order to remove the cosmic rays, the difference of the flying time between the positive and negative track, $|t_+ - t_-|$, is required to be less than 4.0 ns. Information from the TOF system is used to identify protons. Both tracks are required to be not identified as a π or a K by the TOF, *i.e.* the measured flying time and the expected flying time assuming the track to be proton, pion, or kaon should satisfy the following requirement, $|t_{meas} - t_{exp}(p)| < |t_{meas} - t_{exp}(\pi)|$ and $|t_{meas} - t_{exp}(p)| < |t_{meas} - t_{exp}(K)|$. Meanwhile, since $J/\psi \rightarrow p\bar{p}$ is a two-body decay, the $p\bar{p}$ pairs are back-to-back; we require the two-track opening angle to be larger than 175° . Finally, for both tracks, the absolute difference between the measured momentum and its expected value, 1.232 GeV/c, is required to be less than 110 MeV/c.

Figures 1(a)-(d) show the proton momentum distribution for events surviving different selection criteria: Fig. 1(a) is after the particle ID and cosmic rays veto; Fig. 1(b) is after the back-to-back requirement; Fig. 1(c)

is the antiproton momentum after the same cuts; and Fig. 1(d) is the proton momentum distribution after selecting the momentum of antiproton with ± 110 MeV/c cut. From this last figure it is apparent that most of the background has been rejected.

III. BACKGROUND ESTIMATION

Two methods are used to estimate the background level. Method one uses a $J/\psi \rightarrow \text{anything}$ MC sample that is produced using the Lund-charm [12] generator. From this sample the level of background events in the data is determined to be about 1.5% of all selected events. This background is mainly due to $J/\psi \rightarrow \gamma p\bar{p}$, $J/\psi \rightarrow \pi^0 p\bar{p}$ and $J/\psi \rightarrow \gamma \eta_c$, $\eta_c \rightarrow p\bar{p}$. Before application of the proton momentum requirement, the background level is about 1.7%. This study indicates that there is little background for high momentum values, but some at lower momenta, as can be seen in Fig. 1 (d).

In method two, possible two-body background channels, such as $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$, $J/\psi \rightarrow K^+K^-$, $J/\psi \rightarrow \pi^+\pi^-$, $J/\psi \rightarrow \gamma p\bar{p}$, $J/\psi \rightarrow \pi^0 p\bar{p}$, and $J/\psi \rightarrow \gamma \eta_c$, $\eta_c \rightarrow p\bar{p}$ are considered and generated according to the branching ratios listed in PDG(2002) [14]. The total background level for these events surviving the $J/\psi \rightarrow p\bar{p}$ event selection criteria is about 0.7%.

Since the background level is very small, we do not subtract the background but use 1.5% as the uncertainty of the background in the branching ratio measurement.

IV. EFFICIENCY CORRECTION

Since there are imperfections in Monte Carlo simulation, particularly when it simulates the tail of momentum resolution and TOF resolution, which will affect the efficiencies of momentum cuts and particle ID. In order to reduce systematic error as much as possible, the correction on MC efficiency is needed. Since both momentum resolution and TOF resolution are $\cos\theta$ dependent, when we put cuts on momentum and TOF, the efficiency will depend on the angle θ . A reweighting method is used to do the efficiency correction. We define a $\cos\theta$ dependent weight factor (or correction factor) $wt_j(\cos\theta)$ as:

$$wt_j(\cos\theta) = \epsilon_j^{data}(\cos\theta)/\epsilon_j^{mc}(\cos\theta),$$

where j represents the j th selection requirement, θ is the polar angle of p or \bar{p} , and ϵ stands for efficiency. When the weight functions are obtained, phase space MC generator is used and 500,000 events are generated. Since the weight is obtained in each small bin of $\cos\theta$, the weight function will not depend very much on the actual angular distribution of generated events. To determine the weight for a given variable, the other, uncorrelated requirements are made more stringent to provide a pure sample. When the correlation among different selection

criteria is so small that it can be ignored, the efficiency of the data can be expressed by the reweighted MC efficiency as:

$$\begin{aligned} \epsilon_{data}(\cos\theta) &= \epsilon_X \prod_{j=1}^n (\epsilon_j^{data}(\cos\theta)) \\ &= \epsilon_X \prod_{j=1}^n (\epsilon_j^{mc}(\cos\theta) \times wt_j(\cos\theta)) \\ &= \epsilon_X \prod_{j=1}^n \epsilon_j^{mc}(\cos\theta) \prod_{j=1}^n wt_j(\cos\theta) \\ &= \epsilon_{mc}(\cos\theta) \times wt_{tot}(\cos\theta), \end{aligned}$$

where ϵ_X is the part of the efficiency which is not corrected; it is due to track reconstruction, geometry acceptance, etc, and its uncertainty can be determined using another method (see Sec. VII below). The total correction factor wt_{tot} is:

$$\begin{aligned} wt_{tot}(\cos\theta) &= \\ wt_p(\cos\theta) \times wt_{\bar{p}}(\cos\theta) \times wt_{pid}(\cos\theta) \times wt_{\bar{p}id}(\cos\theta), \end{aligned}$$

where wt_p and $wt_{\bar{p}}$ are the weights for the proton and antiproton momentum requirements, while wt_{pid} and $wt_{\bar{p}id}$ are the weights for the particle identification requirements on proton and antiproton.

V. ANGULAR DISTRIBUTION

With $\epsilon_{mc}(\cos\theta)$ denoting to the efficiency obtained from Monte Carlo and $wt_{tot}(\cos\theta)$ for the total correction function of the efficiency, we fit the angular distribution of the data with the function $f(\cos\theta)$,

$$f(\cos\theta) = A \times (1 + \alpha \cos^2\theta) \times \epsilon_{mc}(\cos\theta) \times wt_{tot}(\cos\theta)$$

where A is a constant.

Fig. 2(a) shows the angular distributions for 500,000 phase space MC events and Fig. 2(c) for the sideband background which is from p, \bar{p} momentum distribution from 1.00 GeV/c to 1.10 GeV/c. Fig. 2(b) shows the total weight curve and Fig. 2(d) shows the result of fitting to the angular distribution of the data. The fit to the angular distribution of data gives

$$\alpha = 0.676 \pm 0.036,$$

where the error is statistical only.

VI. BRANCHING RATIO OF $J/\psi \rightarrow p\bar{p}$

After the final selection, the number of signal events is

$$n_{data}^{obs} = 63316$$

The Monte Carlo generator, which includes the angular distribution of $\frac{dN}{d\cos\theta_p} = 1 + \alpha \cos^2\theta_p$ with $\alpha = 0.68$

the momentum of proton after different cut

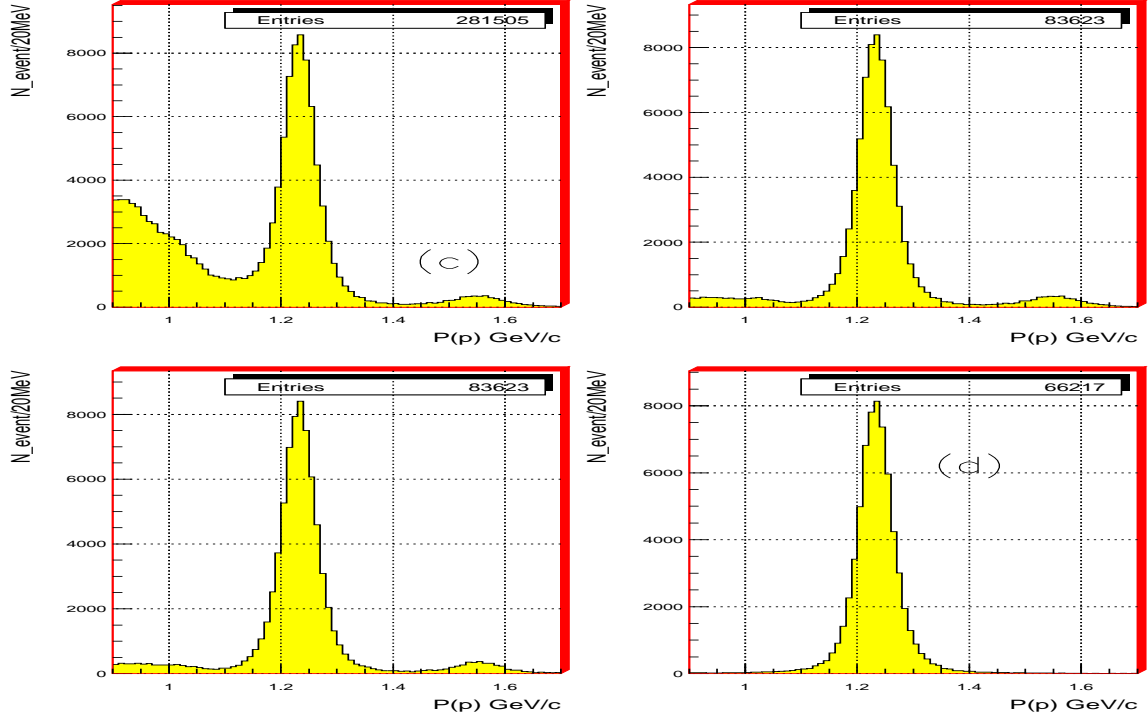


FIG. 1: The proton momentum distribution for events surviving different selection criteria: (a) after particle ID and cosmic ray veto; (b) after the back-to-back requirement; (c) the corresponding antiproton momentum distribution; (d) the proton momentum distribution after selecting the antiproton momentum as shown in(c).

obtained from above fit, is used and 50,000 events are generated to estimate the selection efficiency for branching ratio calculation. The MC-determined selection efficiency ϵ_{mc} , including the effect of reweighting, is $\epsilon_{mc} = (48.53 \pm 0.31)\%$ and the branching ratio is determined to be:

$$Br(J/\psi \rightarrow p\bar{p}) = \frac{n_{data}^{obs}}{N_{J/\psi}^{tot} \times \epsilon_{mc}} = (2.26 \pm 0.01) \times 10^{-3},$$

where $N_{J/\psi}^{tot}$ is the total number of J/ψ in the data sample (57.7×10^6) [13]. The error is statistical only.

VII. SYSTEMATIC ERROR

A. Systematic error of angular distribution

When the fit parameters of the weight curve are changed by 1σ , the fitted value for α changes by 2.6%. This is taken as a systematic error. Another systematic error from tracking reconstruction is determined by using different MDC wire resolution models in the MC simulations. This affects the α value by 5.2%. From a p, \bar{p} momentum sideband study, the uncertainty from background, including background level and background shape, is estimated to be 2.2%. The uncertainties

from other sources such as from the fitting function of $\epsilon_{mc}(\cos\theta)$ are negligible. Adding these contributions in quadrature gives a total effect about 6.2%, i.e.

$$\alpha = 0.676 \pm 0.036 \pm 0.042,$$

where the first error is statistical and the second systematic.

B. Systematic error of the branching ratio

Systematic errors on the branching ratio measurement mainly come from MC statistics, the efficiency uncertainties of the particle ID, the momentum selection, the MDC wire resolution, the uncertainty in α , uncertainties in the background level, and the total number of J/ψ events.

The MC statistics gives a systematic error about 0.6%. As discussed in Sec. III, we do not subtract background but use 1.5% as the uncertainty from the background in the branching ratio measurement. Reweighting is used to correct the PID and momentum cut efficiencies. When the weight curve is changed by 1σ , the branching ratio changes by 0.3%. Different wire resolution models used in the MC produce shifts of 3.6% in the branching ratio. When the channel $J/\psi \rightarrow p\bar{p}$ is simulated, the α value is an input parameter. If we change the value by 1σ ,

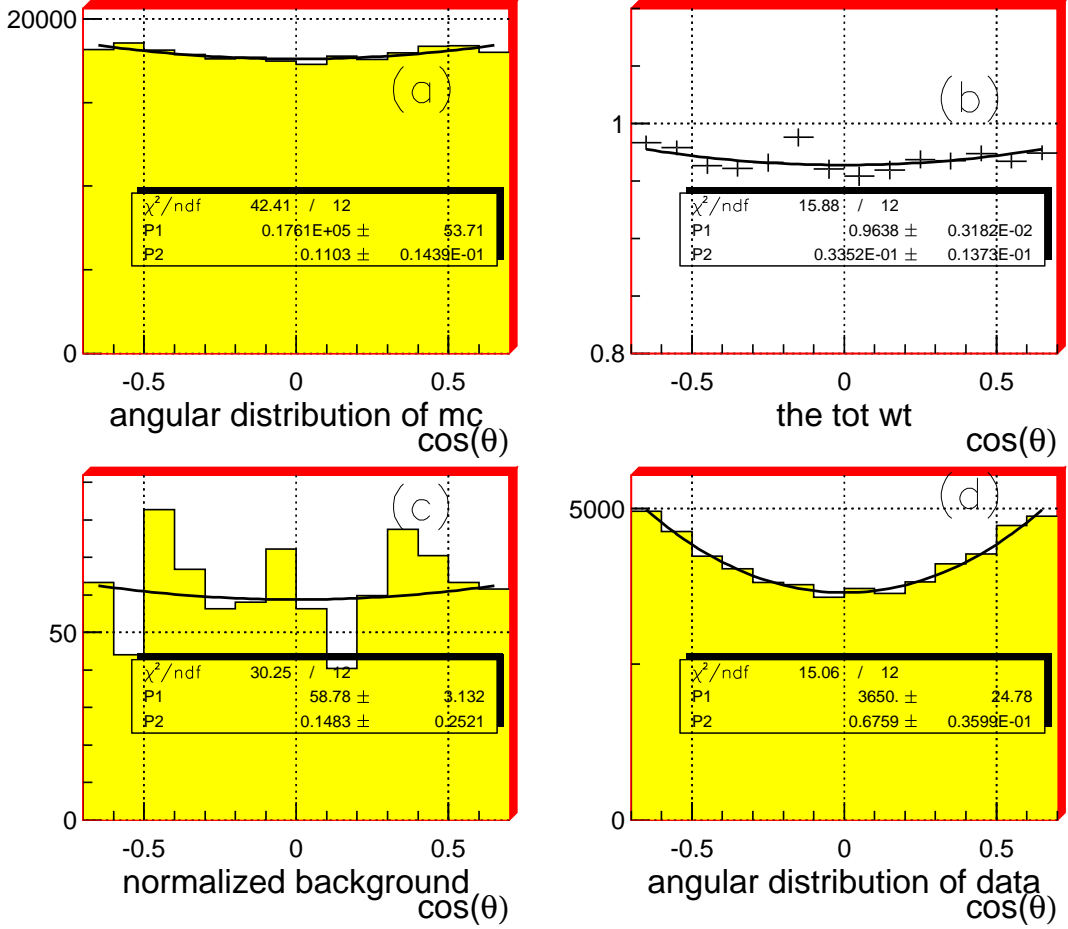


FIG. 2: The (a) angular distribution for MC events; (b) total weight curve; (c) angular distribution of the background; and (d) angular distribution of the data.

the efficiency changes by 0.6%. The total number of J/ψ events is determined to be $(57.70 \pm 2.72) \times 10^6$ [13]; we use 4.7% as the systematic error from this source.

Combining the uncertainties from all sources in quadrature, the total effect on the branching ratio of $J/\psi \rightarrow p\bar{p}$ is about 6.2%, i.e.

$$Br(J/\psi \rightarrow p\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3},$$

where the first error is statistical and the second systematic.

Table III lists the systematic errors from all sources.

VIII. SUMMARY

The channel $J/\psi \rightarrow p\bar{p}$ is studied with 57.7×10^6 J/ψ [13] events. The branching ratio and angular distribution are measured. The branching ratio is within one σ of the PDG world average value and the angular distribution α is in good agreement with the theoretical prediction that includes the effects of non-zero quark masses [8].

TABLE III: The systematic errors

Sources	Effect on α	Effect on Br.
MC statistics	—	0.6%
background	2.2%	1.5%
wire resolution	5.2%	3.6%
reweighting	2.6%	0.3%
α value	—	0.6%
J/ψ number	—	4.7%
total effect	6.2%	6.2%

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